Internal Wave Climate: Shelf to Deep Ocean

Murray D. Levine
Phone: (541) 737-3047; e-mail: levine@oce.orst.edu

Timothy Boyd
Phone: (541) 737-4035; e-mail: tboyd@oce.orst.edu

104 Ocean Admin Bldg
College of Oceanic & Atmospheric Sciences
Oregon State University
Corvallis, OR 97331

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LONG-TERM GOAL

The long-range goal of this research is to understand the variation in the kinematics and dynamics of the internal wave field from the deep ocean to the continental slope and shelf.

OBJECTIVES

Specific objectives of this project include: formulating an improved statistical description of the internal wave field, and understanding the flux of energy into and through the littoral zone.
Knowledge of the internal wave field is important to understand and model mixing and turbulent dissipation, and to predict fluctuations in acoustical propagation and optical properties.

APPROACH

We are addressing these objectives using two different strategies: a detailed analysis of the high-resolution CMO / Primer mooring data; and a general analysis of historical data, primarily from the Oregon coast.

The CMO / Primer data will provide the basis for developing a statistical framework for describing the littoral internal wave field. The Oregon coast historical data, while not as densely sampled in time and space, will span a broader range of background conditions which will allow us to generalize our description of the wave field. This effort will begin the process of formulating an internal wave climatology on the continental shelf.

WORK COMPLETED

Data from the CMO / Primer mooring has been archived and distributed to other participants in the experiment.

Historical moored data from the Oregon coast has been obtained from Dale Pillsbury and Jane Huyer.

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Spectral analysis has begun.

Presentations have been made at the Ocean Sciences Meeting (Feb 1998), SAS Primer Workshop (Feb 1998), OSU Seminar Series (Mar 1998), CM&O Workshop (Sept 1998), EPOC meeting (Sept 1998) and Internal Solitary Wave Workshop (Oct 1998).

RESULTS

We are focusing the analysis on two data sets: the CMO / Primer mooring observations, and the Oregon coast historical current meter data.

Oregon Coast results:

The data have been obtained and archived. We are in the early stages of analysis. Initially we are focusing our attention on lines of moorings that span from the deep water to the continental shelf in order to study the transition of the internal wave field from the Garrett-Munk (GM) open ocean description. Preliminary results indicate that the largest deviations from the GM spectrum occur in the upper ocean and in shallow water depths.

CMO / Primer results:

The internal wave spectral continuum at frequencies between semidiurnal tide and 1 cph has a shape similar to the GM spectrum. The internal wave energy level per unit volume is within a factor of 2 of the GM level when using the local N scaling. Since the water depth is much shallower than the open ocean, the energy per unit area is about a factor of 10 less than the GM. The vertical structure is dominated by mode 1 to a greater extent than in the GM formulation. In terms of the GM description the equivalent mode j_* is about 1-- lower than the GM $j_* = 3$.

At frequencies above 1 cph the spectrum becomes whiter before finally rolling off. A spectral plateau or peak just below N is a feature often seen in upper ocean observations, especially in shallow water. In our data a significant amount of the energy in this spectral region is due to nonlinear internal wave packets. To determine the effect of the packets on the background spectrum, we have estimated spectra at times when these tidally-generated waves were absent. The energy in the high frequency plateau is reduced, but not eliminated. Some of this high-frequency energy appears to still be due to the random internal wave field; quantitative estimates will be forthcoming soon.

The nonlinear internal wave (NIW) packets are interesting and important in their own right. Packets have been observed throughout the world, primarily on continental shelves and are sometimes referred to casually as solitary waves, solitons, or solibores. These waves are generated by the interaction of the tide with topography, such as sills and continental slopes. In recent years NIW have commanded the attention of a diverse group of researchers studying: geophysical fluid dynamics, acoustics, ocean optics, sediment transport, plankton advection and vertical mixing.

As an introduction to the NIWs observed at CMO / Primer, it is instructive to look at the NIWs in the context of the oscillations at other scales that are due to other processes. A 5-day time series of northward velocity from the mooring in 70 m of water is shown in Figure 1. The low frequency is dominated by the semidiurnal tide, which is primarily barotropic. NIWs appear as high-frequency packets separated by about 12 hours during the first 2 days; the NIWs are nearly absent in the next 3 days. The background oceanic conditions do not change much during this time, but the NIW signal does.

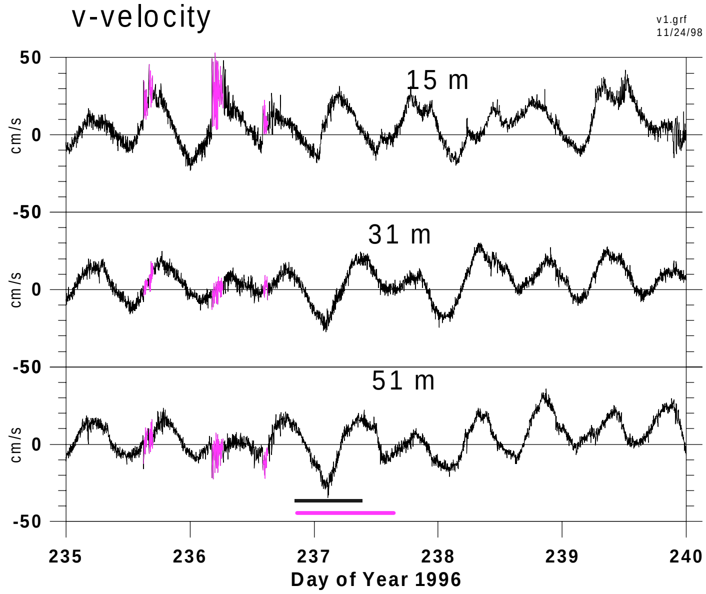

Figure 1

Expanding the time axis for one packet (Figure 2), we can see the packet is composed of 6 large “solitons”. (Note: we use the term soliton here for convenience rather than to imply that these satisfy the precise fluid mechanical definition of soliton.) The velocity pulses are indeed significant, reaching 40 cm/s in the upper layer. The vertical structure is consistent with mode 1 behavior with a zero-crossing near 30 m depth. Each soliton has a temporal width of about 10 minutes. The corresponding temperature signal of this packet shows that the solitons are waves of depression with vertical displacements of up to 15 m.

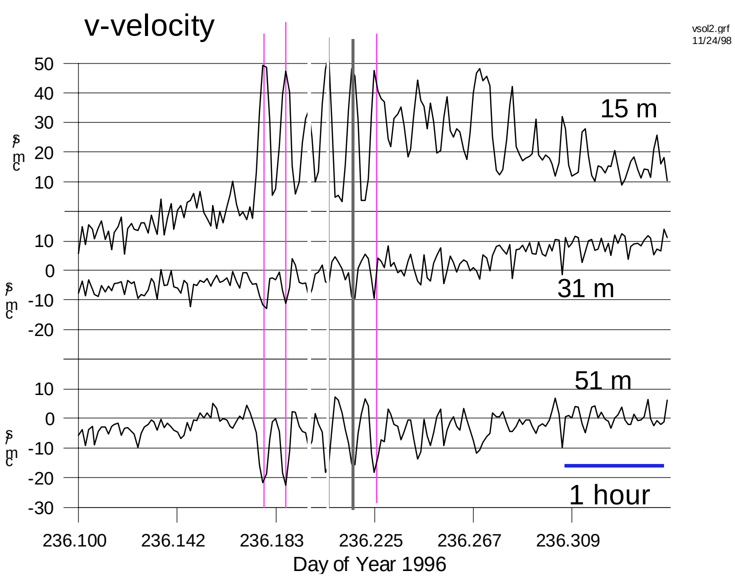

Figure 2

Despite the regularity of the barotropic tide, the characteristics of the NIWs vary in time. To summarize this variability, statistics were compiled of all packets that were observed during a 60 day period from July to September 1996 (Figure 3).

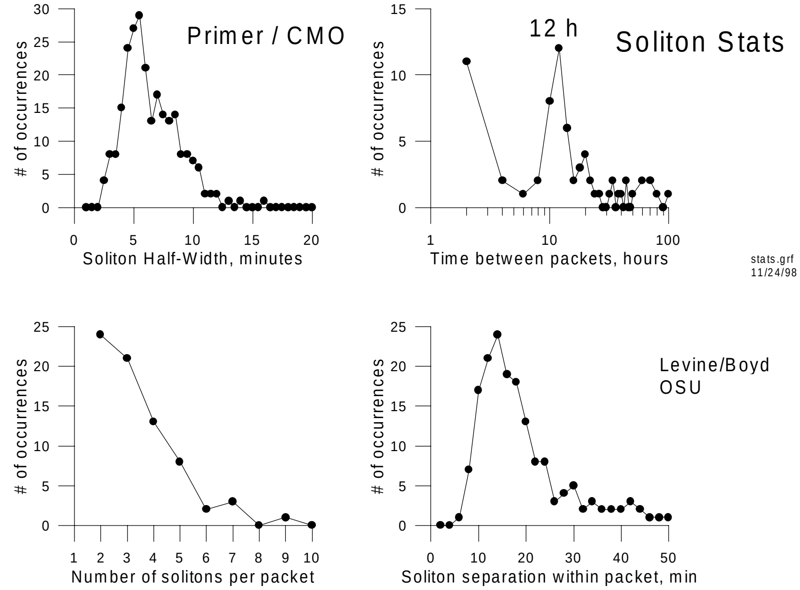

Figure 3

These statistics are based on certain subjective criteria in defining a signal as a soliton. There are undoubtedly many less energetic NIWs that escaped our census. Packets are most often separated by about 12 hours as expected for semidiurnal generation. However, there are often gaps in this regular generation, as seen in Figure 1, and the separation between packets is often longer than 12 hours. The number of solitons in a packet also varies––most packets contain only 2 or 3, and they are not always rank ordered. The temporal width of the individual solitons was peaked around 10 minutes, with a significant number that were "wider". No attempt has yet been made to account for the effect of the low frequency tidal flow on this estimate of width. The propagation direction of the packets was determined by looking at the velocity in the upper layer. On average the waves were propagating onshore (northward) perpendicular to the topography. However, there was a significant variability in direction of +/- 45 degrees. Part of the explanation for the observed variability can be found by looking at SAR images taken during the observations. Rather than long-crested waves following the mean topography, the images indicate the wave packets are generated from many localized sources. The observed waves are then composed of a sum of interacting wave packets. This spatial complexity does not, however, explain the temporal variability. We suggest that the generation or propagation properties must be sensitive to subtle variations in the stratification, tidal amplitude, etc.

To assess whether the NIWs are important to mixing, the cumulative horizontal kinetic energy (HKE) flux from these packets was estimated. The average flux is about 11 W per meter of crest––the total energy flux (including potential energy) would be about a factor of 2 higher. To determine if this flux is important to mixing, an estimate needs to be made of the distance over which these waves are dissipated. If they are gone after traveling 10 km, then the average dissipation would be 1 x 10^{-3} W/m^2. This value is discounted if they travel farther. Most likely they do not propagate more than 50 km beyond the mooring. Is this a significant dissipation? This remains an active research issue. Comparison with other shelf processes may provide some perspective. Hurricane Edouard passed the mooring site in September and mixed the water dramatically in about 6 hours. If the observed NIWs were to do this mixing, it would take 15 to 30 days!

IMPACT / APPLICATIONS

Internal wave oscillations are a significant source of variability to acoustic propagation and optical

properties. To understand and model these fluctuations, improved statistical descriptions are needed of the complete internal wave spectrum including NIWs. Many of the existing models are based on the GM formulation which may not be accurate on the continental slope and shelf.

TRANSITIONS

The analysis of the CMO / Primer data has been used by partners measuring and modeling acoustic propagation during the experiment (Williams, Henyey, Ewart at APL/UW).   Collaboration continues with other investigators of the CMO experiment, including optical observations by Dickey (UCSB), turbulence measurements by Gregg (UW), and other moored observations by Lentz and Pleuddemann (WHOI).

RELATED PROJECTS

We are deploying a set of moorings on the continental shelf off Oregon in summer 1999 as part of a NOPP project studying wind-driven coastal circulation. We will resolve the internal wave field and be able to compare and contrast with our CMO results.